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A field guide to coastal echinoderms of the Kerguelen Islands

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Abstract

One of the current challenges in today's ecology research is to understand and quantify the effects of climate changes on biodiversity. In order to detect possible trends in biodiversity patterns, it is necessary to conduct long-term observations in various and representative environments. This is always challenging, even more difficult in marine habitats and in the Southern Ocean in particular.

Since 2012, a submarine observatory of the coastal benthos has been in operation in the Kerguelen Islands. Eight contrasting sites are monitored using photo and video surveys, loggers, and settlement plots. To quantify potential changes, several photographic analysis techniques are also complemented by scuba diving and ROV (Remotely Operated Vehicle) observations. Investigator scientists have developed and improved new protocols that will be carried out in the long term by the staff of the National Natural Reserve of the French Southern Territories. In order to provide reliable support of species identification, the Proteker program supported by IPEV, French Polar Institute, is currently developing several field guides that should improve the identification of the main taxa being monitored. In light of their abundance in coastal environments of the Kerguelen Islands, and because they are among the most visible invertebrates and the easiest of organisms to consider for monitoring surveys, we first focused on echinoderms. Results of this first study are presented here.

For each echinoderm species, a spreadsheet provides the species name with synonymies, a description of diagnostic features, the recorded distribution, as well as three different types of illustrations: (i) living specimens in their environment, which is useful for scuba divers, (ii) fresh collected specimens out of water, and (iii) specimens fixed in ethanol. Therefore, species can be identified alive while diving, but also after sampling in the field, and after several years in the laboratory. An assessment of Kerguelen's coastal echinoderms is also given.

Key words: Southern Ocean, Sub-Antarctic Islands, climate changes, frontal shifts, marine protected area, coastal benthos, Asteroidea, Holothuroidea, Ophiuroidea, Echinoidea, Crinoidea, monitoring, scientific diving, beam-trawling, Remotely Operated Vehicle, photo and video surveys, registers of marine species, PROTEKER

Introduction

Climate change in the sub-Antarctic Islands. In the Southern Ocean, and in the sub-Antarctic islands in particular, the multiple effects of climate change are already perceptible and include, among other factors, an increase in sea surface temperature (Mélice *et al*. 2003; Ansorge *et al*. 2009, 2014), a rainfall decrease, an increase in wind speed, and a rise of sunshine hours (Smith 2002, Mélice *et al*. 2003; Rouault *et al*. 2005; Le Roux and McGeoch 2008). Future scenarios predict warmer, fresher, and more acidic sea-waters, in addition to more extreme climatic events and higher amplitudes in seasonal variations (Allan *et al*. 2013; Turner *et al*.

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2014; Gutt *et al*. 2015). All these predicted changes in abiotic, environmental factors are expected to affect marine life (Allan *et al*. 2013; Gutt *et al*. 2015; Féral *et al*. 2016 b). Along with alteration of communities and ecosystem functioning, they might lead to distribution range shifts and even to local species extinctions (Walther *et al*. 2002; Doney *et al*. 2012). They may also allow the establishment of warmer conditions favorable to the arrival of invasive species (Smith 2002; Pendlebury and Barnes-Keoghan 2007; Allan *et al*. 2013; Kargel *et al*. 2014; Molinos *et al*. 2015; Byrne *et al*. 2016). Such environmental changes are particularly expected to impact coastal marine habitats of the Kerguelen Islands (CCAMLR 2008, 2013; Améziane *et al*. 2011; Hureau 2011; Féral and Poulin 2011; Féral *et al*. 2019).

The Kerguelen Archipelago. The Kerguelen Islands [49°20'00"S, 69°20'00"E], also known as the Desolation Islands constitute one of the two emerged parts of the mostly submerged Kerguelen Plateau. They lie 3,900 km southeast of South Africa, 1,950 km from Antarctic and 4,000 km from Australia. The Kerguelen Plateau also emerges 450 km southeast of the Kerguelen archipelago at Heard and McDonald Islands. The Kerguelen Islands (7215 km^2) consist of a main island, the so-called Grande Terre, surrounded by 300 smaller islands and islets. France maintains Port-aux-Français station with the permanent presence of some 100 engineers and researchers during the austral summer, and 50 in winter, to support research activities.

The Kerguelen Archipelago emerges in the flow of the Antarctic Circumpolar Current, at the confluence of several water masses (Antarctic Surface Waters, Polar Front Surface Waters and Sub-Antarctic Surface Waters), close to the Antarctic convergence. Latitudinal shifts of these water masses with distinct characteristics ($T^{\circ C}$, $S^{\circ}/_{OO}$, nutrients, plankton) will result in drastic environmental changes that would affect coastal marine biodiversity and ecosystem functioning (Park *et al*. 2014; Féral *et al*. 2016 a; Féral *et al*. 2016 b). To identify and quantify such potential trends, changes must be recorded through appropriate long-term monitoring.

Conservation issues. In 2006, the National Nature Reserve of the French Southern Territories (RNN-TAF) was created by a French inter-ministerial decree (*n° 2006-1211 of 3 October 2006*). In 2016, a second ministerial decree *(n° 2016-1700 of 12 December 2016)* extended the RNN-TAF to most of the French Exclusive Economic Zone (EEZ). For the Kerguelen Islands alone, the area covered by the Marine Protected Area (MPA) of the RNN-TAF increased from 4,998 km^2 to 389,829 km^2. In addition to the extension of the Kerguelen MPA, all the coastal marine area has now gained the status of enhanced protection. As a consequence, nature managers of the RNN TAF are in need of new scientific data to support relevant conservation planning.

Since the discovery of the Kerguelen Islands, marine coastal habitats have been little affected by direct anthropogenic disturbance and no invasive species have been observed yet. Except in the surroundings of Port-aux-Français station, the unique effect of human activities on coastal marine habitats could be the introduction of migrating salmonids although this change has not yet been evaluated (Lecomte *et al*. 2013). Coastal marine habitats and their communities are still pristine marine ecosystems, priceless sentinels of climate change. Specific marine ecological and oceanographic conditions due to the close proximity of shifting hydrological fronts make the Kerguelen islands a unique observation site providing valuable baseline for assessing the effects of climate change on marine communities and ecosystem functioning. Significant effects are expected on local benthic communities, members of which have limited regulatory abilities (Stenni *et al*., 2017; Gutt *et al*., 2018; Cárdenas *et al*. 2018).

The IPEV-1044 program Proteker

Environmental data must be continuously recorded for interpreting ecological changes, predicting potential effects on marine life, and setting up appropriate management plans. Such objectives can only be achieved by implementing a long-term and cross-disciplinary observing system of ecological changes (Gutt *et al*. 2018). For this purpose, the IPEV program n°1044 Proteker was conceived as a multidisciplinary approach including oceanographic measurements, benthic dynamics survey, as well as genetic, trophic, and eco-physiological analyses (Féral *et al*. 2016 b; Féral *et al*. 2019; Saucède *et al*. 2019). The objectives of the program are to identify, monitor, and predict changes in marine coastal ecosystems as a basis for vulnerability assessments and appropriate management planning.

After exploring the coastal zone around Grande Terre by scuba diving down to 20 m depth and using beam trawls and R.O.V. down to 100 m depth for sampling and video surveys, eight sites representative of Sub-Antarctic habitats were selected to monitor ecological changes. They were equipped with temperature and salinity loggers, and with settlement plots (Féral *et al*. 2016 a, 2016 b, 2019; Saucède *et al*. 2019).

A field guide to coastal echinoderms of the Kerguelen Islands

The need for sub-Antarctic field guides. The examination of existing field guides to the marine fauna and flora of the Southern Ocean shows that biodiversity of the Antarctic zone has been more extensively treated than the sub-Antarctic, (Brueggeman 1998; De Broyer *et al*. 2014; Rauschert & Arntz 2015; Schories & Kohlberg 2016). This deficiency applies to the echinoderms to which Antarctic volumes have been dedicated (Neill *et al*. 2016 [Asteroidea]; David *et al.* 2005 [Echinoidea]). A selection of taxa from the fauna and flora of the Kerguelen Islands has been described in the 'Food and Agriculture Organization of the United Nations (FAO) species identification sheets for fishery purposes' (Fischer & Hureau 1985a, 1985b) but echinoderms are not part of them as these guides include marine species believed to be of potential interest to fisheries. So far, sub-Antarctic echinoderms of the Kerguelen Plateau were mainly described in the field guide from Heard and McDonald islands (Hibberd & Moore 2009) which includes common offshore taxa, but coastal species were not included. There is an overall need for a guide dedicated to marine invertebrates of the sub-Antarctic Islands, particularly in the subtidal area. Such a guide would be in line with objectives of RNN-TAF conservation planning (Koubbi *et al* 2016) and several application lines are expected. A comprehensive guide is a prerequisite to a effective monitoring of coastal marine areas and it can also prove to be useful to fisheries controllers of the French Southern Territories for an accurate management of by-catch.

In the framework of program Proteker, past species inventories were completed by new samples collected down to 100 m depth and images of specimens alive and/or after sampling were taken when feasible. The objective was to produce field guides useful to non-specialist scientists, environment officers, and non-governmental partners who are tasked with assessing the state of coastal habitats, fisheries resources and benthic communities. The guides will promote the use of standardized survey methods and analytical procedures allowing comparable results across monitoring sites in the Kerguelen Islands, as well as between the Kerguelen Islands and other sub-Antarctic islands. They are not intended to deliver targeted management recommendations but they will highlight the need to apply useful and repeatable measures for a sustainable management. The guides should contribute to (1) establishment of a long-term monitoring of coastal habitats to detect environmental changes and (2) estimating the status of coastal communities and assessing the potential impact of human activities in order to provide suitable conservation recommendations.

Taxa included in the guide. Assessing biodiversity cannot be reduced to monitoring only rare and endangered species, either under legal protection or not, also known as the "remarkable biodiversity". It also requires the documentation and the preservation of "ordinary biodiversity" even when it is not possible to assess it all at species level. Selection of taxa must be based on both theoretical assumptions and practical considerations.

From a theoretical point of view, "ordinary biodiversity" is the main source of services that ecosystems may provide to the society. Moreover, redundancy in ecosystem functioning is mainly supported by "ordinary species" which may be interchangeable with each other when involved in similar biotic interactions. This is reinforced by the practical reason that taking all species into account in a monitoring program is not feasible. In addition, to be effectively monitored, species should not be rare, they must be easily recognizable *in situ*, on photoquadrats or in a trawl catch, even by non-specialists. In sub-Antarctic waters, a number of echinoderms, together with sponges, ascidians and mollusks meet such requirements.

A pilot project: the echinoderms of the Kerguelen Islands. Considering their importance and abundance in coastal environments of the Kerguelen Islands, and because they are among the most visible invertebrates, we first focused on echinoderms; the case study is presented here.

During the campaigns of program Proteker, echinoderms were collected between 0 and 100 m by scuba diving (until 20m depth) and beam trawling (until 100m depth). A total of 45 different species was identified. The Asteroidea represent the most abundant and diversified class with 19 species, 11 families and 5 orders.

The second rank is occupied by the Holothuroidea, with 13 species, 4 families and 3 orders. The Ophiuroidea come on the third line with 9 species, 3 families and 2 orders. There are only 4 species of Echinoidea, 3 families and 3 orders, while Crinoidea is only represented by a single comatulid species (Fig. 1). A preliminary checklist of echinoderm species was established (Table 1) and will be progressively completed on the basis of future samplings.

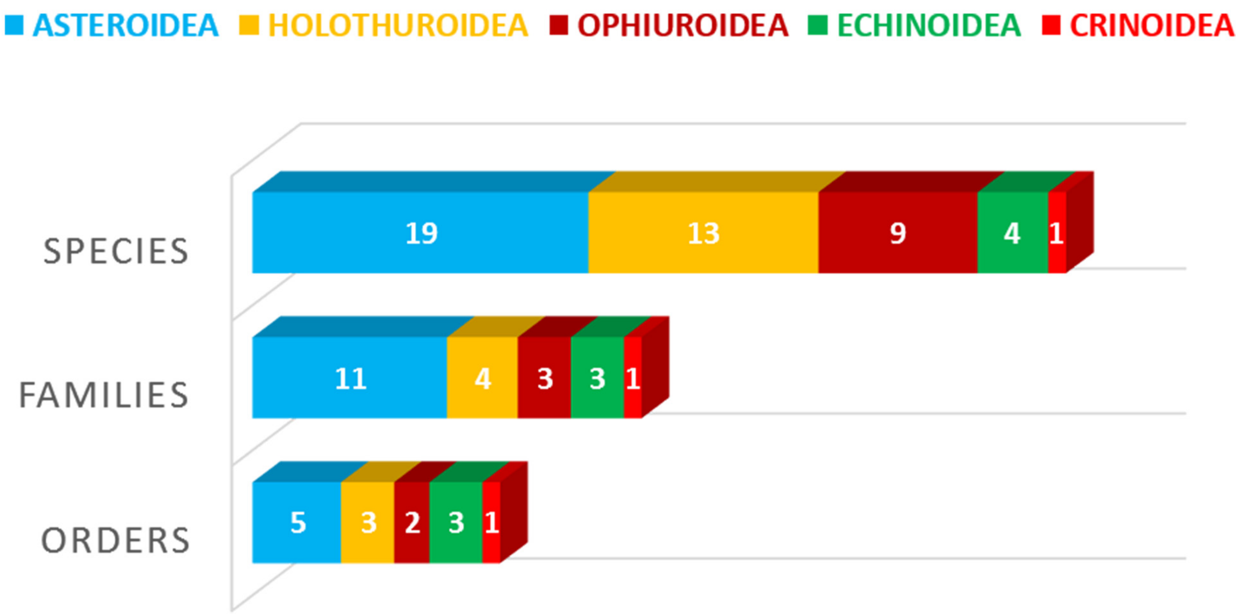

FIGURE 1. Taxonomic distribution of Kerguelen's coastal (0 – 100 m) echinoderms.

TABLE 1. Species list of coastal echinoderms from Kerguelen Islands collected during Proteker campaigns (sorted by orders and families). [*Species with an asterisk have to be confirmed*]

CLASS / Order	Family	*Species*
ASTEROIDEA		
Forcipulata	Asteriidae	*Anasterias perrieri* (Smith, 1876) *Anasterias rupicola* (Verrill, 1876) *Diplasterias* cf.*brucei* (Koehler, 1908) *Diplasterias meridionalis* (Perrier, 1875) *Smilasterias triremis* (Sladen, 1889)
	Labidiasteridae	*Labidiaster annulatus* Sladen, 1889
Notomyotida	Benthopectinidae	*Cheiraster (Luidiaster) hirsutus* (Studer, 1884)
Paxillosida	Astropectinidae	*Bathybiaster loripes obesus* Sladen, 1889 *Leptychaster kerguelensis* Smith, 1876
Spinulosida	Echinasteridae	*Henricia* spp *Rhopiella hirsuta* (Koehler, 1920)
Valvatida	Asterinidae	*Asterina frigida* Koehler, 1917 *Tremaster mirabilis* Verrill, 1879
	Ganeriidae	*Perknaster fuscus* Sladen, 1889
	Odontasteridae	*Acodontaster hodgsoni* (Bell, 1908) *Odontaster penicillatus* (Philippi, 1870)
	Poraniidae	*Glabraster antarctica* Smith, 1876

...Continued on next page

TABLE 1. (Continued)

CLASS / Order	Family	*Species*
	Pterasteridae	*Pteraster affinis* Smith, 1876
	Solasteridae	*Solaster regularis* Sladen, 1889
HOLOTHUROIDEA		
Apodida	Chirodotidae	*Sigmodota contorta* (Ludwig, 1875)
Molpadiida	Molpadiidae	*Molpadia violacea* Studer, 1876
Dendrochirotida	Cucumariidae	*Abyssocucumis abyssorum* (Théel, 1886)* *Cladodactyla sicinski* (O'Loughlin, 2013) *Pentactella laevigata* Verrill, 1876 *Trachythyone denticulata* (Ekman, 1929)* *Trachythyone muricata* (Ludwig, 1875)*
	Psolidae	*Neopsolidium kerguelensis* (Théel, 1886) *Psolidium incertum* (Théel, 1886)* *Psolidium poriferum* (Studer, 1876)* *Psolus antarcticus* Philippi, 1857* *Psolus ephippifer* Thomson, 1876* *Psolus paradubiosus* Carriol & Féral, 1985*
OPHIUROIDEA		
Ophiurida	Ophiocanthidae	*Ophiacantha imago* Lyman, 1878 *Ophiacantha vivipara* Ljungman, 1871 *Ophiolimna antarctica* (Lyman, 1879)
	Ophiuridae	*Ophionotus hexactis* (Smith, 1876) *Ophiura verrucosa* (Studer, 1876) *Ophiura (Ophiuroglypha) ambigua* (Lyman, 1878) *Ophiura (Ophiuroglypha) brevispinosa* H.L. Clark, 1915 *Ophioplinthus carinata* (Studer, 1876)
Euryalida	Gorgonocephalidae	*Gorgonocephalus chilensis* (Philippi, 1858)
ECHINOIDEA		
Cidaroida	Ctenocidaridae	*Ctenocidaris (Eurocidaris) nutrix* (Thomson, 1876)
Echinoida	Echinidae	*Sterechinus diadema* (Studer, 1876)
Spatangoida	Schizasteridae	*Abatus cordatus* (Verrill, 1876)
CRINOIDEA		
Comatulida	Antedonidae	*Promachocrinus kerguelensis* Carpenter, 1888

Principle of the field guide. Invertebrate diversity is high in coastal marine environments and correct taxonomic identification of organisms at family, genus or species level requires some training and experience. One objective of the guide is to allow the staff of the RNN-TAF, fisheries observers, and non-taxonomist scientists to easily identify most common species in the laboratory or in the field, in scuba diving or when sampling at sea using towed gears.

A preliminary version of the guide has been made available online, for testing purposes, through the program Proteker website (*http://www.proteker.net*). A Statement of Work will be prepared for a final version linked to a database. It will be interoperable with other information systems such as biodiversity.aq (*www.biodiversity.aq/*), GBIF (*www.gbif.org/species/search*) and OBIS (*www.iobis.org/*). It will be completed by a printable version and a published one. Other taxonomic groups of importance will be treated the same way.

The home page of the Field Guide offers different entries such as a species list, a taxonomy entry as well as a morphology index (quick-reference pictorial guide). Even if not always intuitive, in order to be as much as possible compatible with existing systems, CCAMLR identification codes are given when possible.

Each species will be shown with photos taken *in situ*, from freshly captured and also from preserved or dried specimens. Classification is given as well as taxonomic references. Maps illustrate the species comprehensive occurrence around the Kerguelen Islands, based on sampling done during the Proteker campaigns in a first step, then complementary data resources will be used in a second step. Descriptions provide information on external and internal anatomical characters, habitats, life history as well as on known distribution in the Southern Ocean. To have a wider view of the distribution, links to information systems are given when they take the considered species into account (links to marine fauna and flora registers). Specific uses as indicator will also be provided when ready. As an example the current information page for the asteroid species *Glabraster antarctica* is provided (Fig. 2) as well as a map that illustrates the species' occurrence around the Kerguelen Islands (Fig. 3).

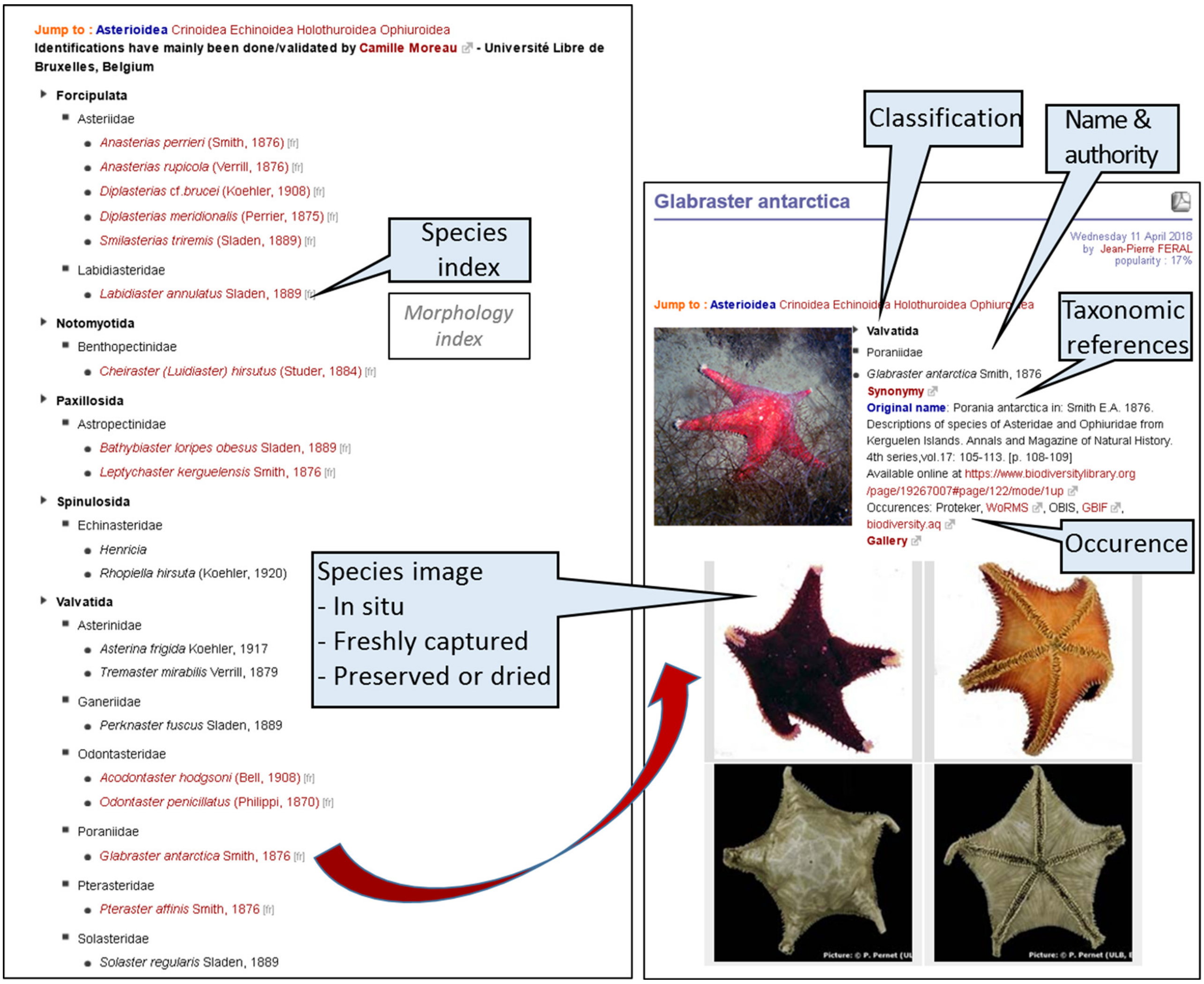

FIGURE 2. Layout of the website working version illustrating the case of the asteroid *Glabraster Antarctica* Smith, 1876. After choosing "Asteroidea", a multiple choices list (left side) open giving access to links to each species. The link drives the visitor to the species sheet (right side). This sheet gives the name and the authority, elements of classification, taxonomic references including links to synonymy and to the original description. It also provide the occurrences around Kerguelen and to information systems in order to have a wider view of the species distribution. Photos illustrate the species *in natura*, freshly captured and also when preserved in ethanol or dried.

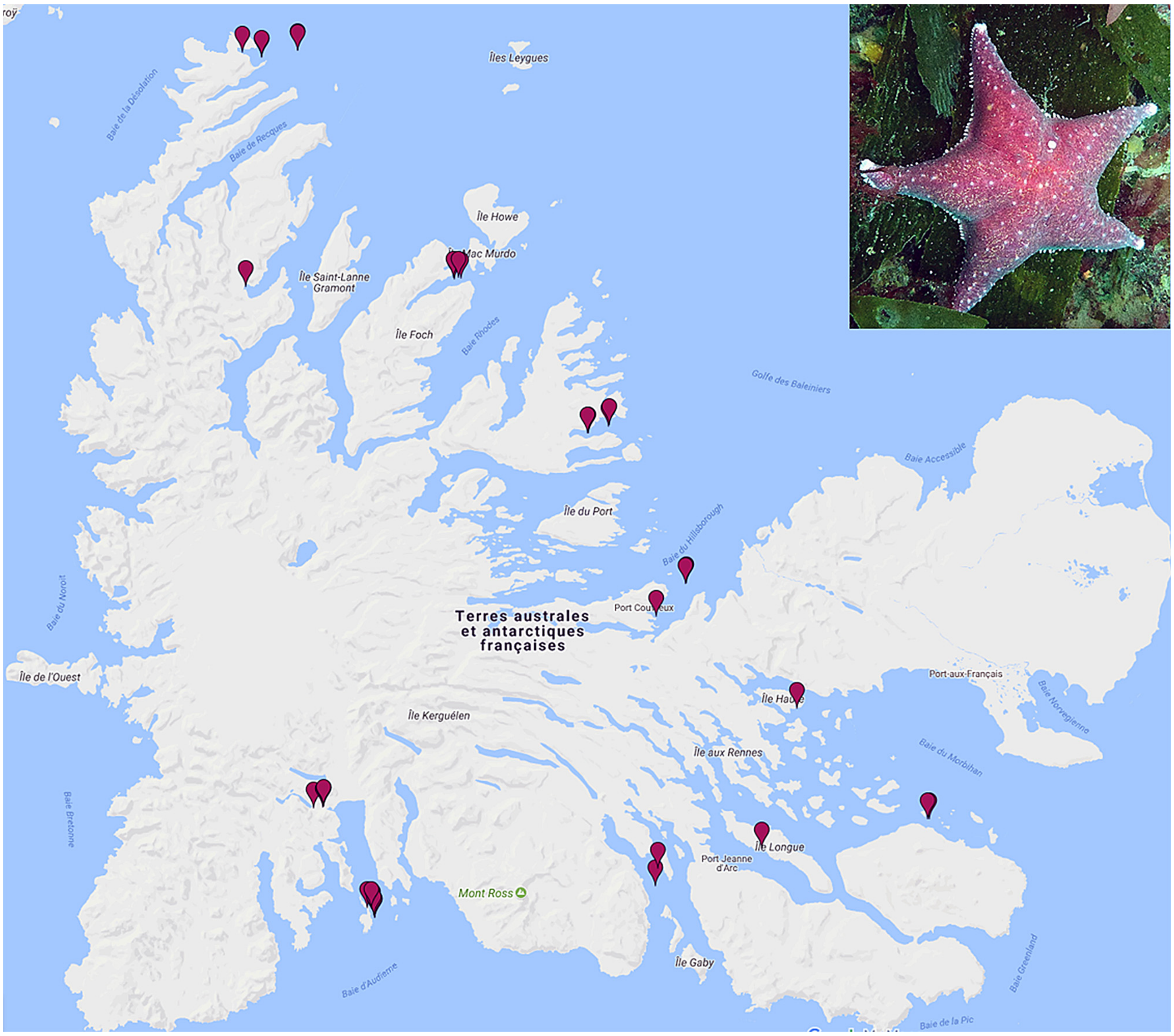

FIGURE 3. Map of the occurrence of *Glabraster antarctica* collected during the Proteker summer campaigns. It will then extended to all available data. The marks are clickable, giving geographic coordinates. [Terres Australes et Antarctiques Françaises = French Southern and Antarctic Islands].

Echinoderms as biological indicators of climate change in the Kerguelen Islands

Indicators of species richness and diversity patterns are central to assessing ecosystem health and evolution in conservation ecology. They represent a common currency for measuring the diversity of life (Magurran 2004). Biodiversity monitoring should not only rely on the measurement of species richness over space and time but also on other metrics including functional diversity, biotic interactions (e.g. predation or parasitism) and their roles in ecosystem functioning (e.g. trophic webs) over time (i.e., beta diversity also known as diversity turnover). Ecological indicators are based on quantitative data to measure biodiversity components, ecosystem conditions and services, or drivers of change, but no single indicator can capture all the dimensions of biodiversity components. Finally, they should prove convenient for diversity monitoring, assessment, and also for decision-making and easily communicating information to policy-makers.

In this respect, functional diversity has been assessed in the framework of program Proteker to model the potential response of species and communities to future environmental changes. Species of echinoderms were targeted to understand their role in food webs based on the combined analysis of gut contents and $\delta^{13}C$ and $\delta^{15}N$ isotopic approach. The ratio of these two stable isotopes allows estimates of the size and plasticity of trophic niches as well as the trophic levels of species in the food web. The quantified size and plasticity of trophic niches are hypothesized as good indicators of species' vulnerability and resilience to variations of food sources. In the Kerguelen Islands, the trophic niches of three common echinoid species of nearshore habitats, *Ctenocidaris nutrix*, *Sterechinus diadema* and *Abatus cordatus* have been quantified to assess their respective resilience to potential changes. Main results show contrasting patterns, some species being at risk under certain scenarios of climate change (Saucède *et al*. 2019). Echinoderm nutrition and metabolism (oxygen consumption) have also been studied under varying temperature, food sources, and sea-water pH conditions using *in situ* experimental designs. Assays in different conditions will also provide indicators of the possible effect of ocean acidification and warming on calcareous organisms under different future scenarios of Southern Ocean conditions.

Finally, population genetics and phylogeographic studies are powerful tools for measuring levels of endemism and connectivity, current and past, between populations of the Kerguelen Islands and the rest of the Southern Ocean in a same way than done by Moore *et al*. (2018) for *Glabraster antarctica*. It can also help unreveal the potential occurrence of cryptic species. Such information is crucial to evaluating the level of vulnerability of each taxon. Phylogeographic studies were performed on crinoids (Hemery *et al*. 2013), on the echinoids *Abatus cordatus* and *Sterechinus diadema* (Poulin and Féral 1995, 1996; Ledoux *et al*. 2012; Saucède *et al*. 2015; Maturana *et al*. 2017; Diaz *et al*. 2018) as well as on target species of fishes, crustaceans, and mollusks (Gérard *et al*. 2015; González-Wevar *et al*. 2017, 2018). Hence, data show that the emblematic echinoid *Abatus cordatus* is endemic to the Kerguelen Islands (probably to the Kerguelen Plateau). In contrast, long-distance biogeographic connections with other sub-Antarctic areas are obvious in the echinoid *Sterechinus diadema* and in crinoids. These contrasted results require further investigations of coastal marine life in the Kerguelen Islands and of faunal relationships with other sub-Antarctic islands such as Marion, Crozet, and Heard and McDonald islands.

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